

RATAN-600 NEW ZENITH FIELD SURVEY AND CMB PROBLEMS

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We present new RATAN-600 data on the synchrotron Galaxy radiation at the PLANCK Mission and WMAP frequencies at high Galactic latitudes upto $\ell = 3000$. The difference between the standard synchrotron template ($\ell < 50$) of the WMAP group and RATAN-600 data was detected with the strong synchrotron "longitude quadrant asymmetry". It may change the WMAP estimates of $z_{reheating}$ from low ℓ polarization data. The polarized synchrotron noise for very deep observations ($\ll 1 \mu K$) at the PLANCK HFI was not detected at $\ell > 200$ scales. "Sakharov Oscillations" in the E-mode ($500 < \ell < 2000$) should be well visible even at ~ 10 GHz. The polarized noise from relic gravitational waves ($\ell \sim 80$) may be confused with B-mode of synchrotron Galaxy polarized noise at the frequencies below 100 GHz, but there are no problems at HFI band.

1. Introduction

The synchrotron and cosmology synchrotron noise from the Galaxy is one of the background screens between the early Universe and the observer. But for polarization experiments this screen may be the most dangerous due to possible high and frequency-dependant E- and B-modes of polarization (up to 70%).

It is not easy to extrapolate available nice maps of the Galaxy synchrotron emission from decimeter low resolution data to PLANCK frequency and to the scales important for Cosmology. The first problem- unknown variations of spectral index with frequency and space, the second- correction for Faraday effect.

The first broad review of the problem was done by M. Tegmark (Tegmark et al., 1999), with estimation of the range of possible effects in the Cosmology important part on the frequency- scale plane. The so cold "Pessimistic", "Middle", and "Optimistic" variants were suggested.

Just after this paper we began to accumulate data on the Galaxy background with RATAN-600 multi-frequency receivers array (~ 30 channels in the 0.6 GHz - 30 GHz band in I, L, R, U, Q Stocks parameters and with different resolution from few arc seconds to few arc minutes.

Some preliminary results have been already published (Parijskij, 2000, 2003, Parijskij and Berlin, 2002; Parijskij and Bursov, 2002; Parijskij and Novikov, 2004). They were connected with spinning dust problem and new limit was found for this screen, much below Tegmark "Pessimistic" case at least at $\ell = 1000$, most

important for CMB E-mode of polarization. New limit was also found for magnetic dust polarization, suggested by Princeton group recently. "Faraday" Galaxy noise was checked at LFI band. This noise can destroy the purity of the theoretical $\langle B \rangle = 0$ requirements for Thomson scattering.

Several recent experiments demonstrated, that synchrotron Galaxy noise has to be studied deeper, than before by several reasons (Naselsky et al., 2003)

1. The unexpectedly high Thomson scattering between the recombination epoch and observer, deduced from very strong polarization at low ℓ . It contradicts Ly-breaks results and requires new population of $z \gg 6$ objects for early ionization of the Universe. Several alternative interpretations appeared in literature, and Galaxy polarization is in this list.

2. Strong interest in the processes of $z=1000$ recombination increases the importance of the polarization measurements of "Sakharov Oscillations" and many groups are waiting for much better information on the Galaxy polarization data.

3. The fundamental check ("experiment cruces") of the Inflation scenario- discovery of relic grav. waves. B-mode polarization at $\ell \sim 100$ was suggested as the direct indication of the existence of the primordial grav. waves, (Zaldarriaga, 1995) predicted by I. Novikov in 60-ties. The reality of this experiment depends on the power of Synchrotron noise (which has $\langle B \rangle = \langle E \rangle$, contrary to scalar Thomson effect, with $\langle B \rangle = 0$) at $50 < \ell < 1004$ band.

4. The primordial magnetic field may be traced through polarization measurements by Faraday effect at $z=1000$ and by detection of the large (larger than

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$z=1000$ horizon) polarization scale-inflation induced magnetic field. Again, Galaxy polarization limits the accuracy of such, sub-micro K effects at $30 < \ell < 200$ scales. This limit well we do not know yet.

5. After "ARHEOPS" experiment, with detection of strong polarization from the Galaxy dust screen at HFI band, we have to find how far we can go to the LFI band, to be in the best place, between Synchrotron and Dust noise ("Scylla, f^{-3} , and Haribda, f^2 ,-situation). The better information on the synchrotron, the better estimates of effects from other screens, including the most uncertain polarized "spinning dust" one.

With our 600m- aperture reflector, RATAN-600, we have no limitation in angular resolution even at 1 GHz at all scales important for Cosmology and all $\ell > \ell_{max}$ for PLANCK HFI may be checked on the synchrotron by observations at $f \ll f_{PLANCK}$. To be as deep in pixel sensitivity as possible, we selected limited portion of the sky ($f_{sky} = \Omega/4\pi = 0.01$) and exposed each pixel in this field as long as ~ 1 Day pixel at $\ell = 200$ scales. It may be compared with ~ 200 seconds for PLANCK mission 2007 and 47 seconds for WMAP. f^{-3} factor solves the sensitivity problem. Indeed, even 10mK data at 1GHz correspond to 10 nano-K at 100GHz, main HFI frequency.

Full data will be presented to PLANCK consortium, but the most important results will be given here.

2. Observations

All RATAN-600 (Parijskij, 2003) observations were done in the standard one-sector mode (North sector) with the secondary mirror N1. This mirror (parabolic cylinder) was equipped by multi-frequencies receivers array, installed along the focal line. In the standard transit mode of observations, the source image is moving along this line, and in ~ 1 minute frequency spectrum of Sky of the beam size at all 31 channels appears at the common backend. 0.6 GHz, 1 GHz, 2.4 GHz bands were divided into 8 independent channels; 3.9 GHz, 7.7 GHz, 12 GHz and 21.8 GHz had cryo-HEMT receivers. At the 30GHz we used 6- feeds matrix HEMT receivers with MMIC technology, and CMB polarization in the Stocks Q parameter were accumulated. All $f > 2.4$ GHz receivers had few mK NET, with best sensitivity at 3.9GHz ($\sim 2\text{mKs}^{1/2}$). All receivers at $f < 3.9$ GHz had 10-30mK NET (<http://www.sao.ru>; Parijskij and Korolkov, 1986; Berlin and et al., 2000).

Local zenith field was selected by several reasons. At zenith instrumental aberrations do not exist and (Stotsky, 1972) there are limitation in the size of the receivers array. At zenith the orientation of the main surface panels is correct, and no "Diagonal errors" appear (Braude et al., 1972). At 45 degrees inclination, the random panel errors are less by $\sqrt{2}$. During the panelsurface adjustments, the radius of panels has been optimized to reduce the "panel curvature error" in the zenith mode.

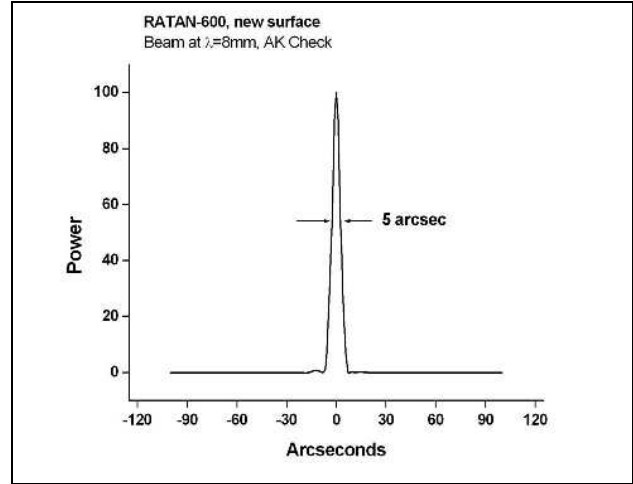


Fig1. The shape of the one-sector beam at the highest frequency, 32 GHz, after re-surfacing of all panels and with new accurate panel adjustments system. The panel r.m.s. error was improved by factor 5, that reduced the wide angle scattering at 1 cm

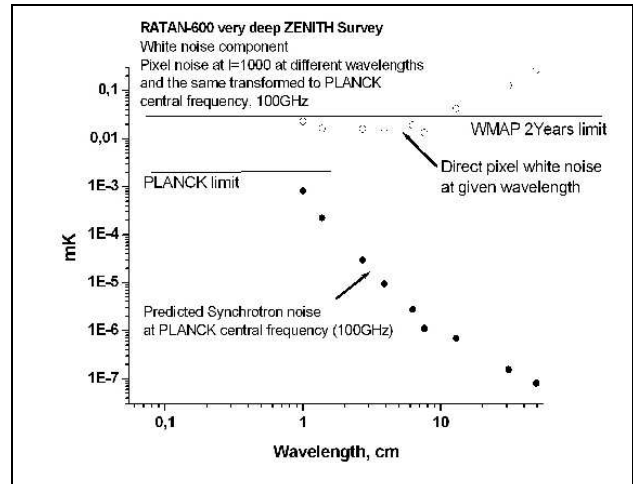


Fig2. It demonstrates, that white noise really does not limit the accuracy of detection Galaxy Synchrotron noise, if we extrapolate it to PLANCK HFI.

The transit time of the $\ell = 200$ scale at zenith was about 500 seconds, and sub-mK white noise pixel sensitivity may be expected at all frequencies in the single day transit. The white noise component at all frequencies in the accumulated data was much below 1mK. For the synchrotron noise, 1mK at 7.6 cm corresponds to 20 nano-K at PLANCK frequency 150 GHz, and $20\mu\text{K}$ at WMAP frequency 23 GHz, and we were not limited by white noise at $\ell < 200$.

The $1/f$ noise and interference are the real limitations. The sum and difference between 2 groups of observations were used to find their effects. Up to 500 24-hours daily scans were carefully analyzed, and C_ℓ - structure of the real noise was estimated. At high ℓ this noise is below white noise component, at $\ell > 200$ it dominates at all frequencies with the slope in the FFT

of the 14-scans close to -1. The standard rule for Galaxy screens- $C_\ell \sim \ell^{-3}$, and at very big scales these screens dominate at all frequencies.

The conversion from T_a to T_b for given pixel at given ℓ needs the beam de-convolution. WMAP results are too noisy for reconstruction of the T_b maps at $\ell > 50$. We decided to use theory at high ℓ . To simplify the task, we realized CMB model of the sky, using standard HEALPIX algorithm up to $\ell = 3000$, convolved it with new version of RATAN-600 beam (Majorova, 2000) to simulate 24-hours transit scan with different 2D- beams from 30GHz to 0.6GHz and compared the dispersion of convolved data with the not convolved one. Simple dispersion analysis does not show very strong effect, it is due to dominant role of low ℓ CMB anisotropy noise in the dispersion. From the FFT of the convolved and not - convolved sky map we can find the correction factor (T_a/T_b ratio) for any given scales or ℓ .

As we expected, the convolution effect is small at high frequencies, medium at low frequencies and low ℓ , but very strong at high ℓ and low frequencies.

wave, cm	ℓ 1000	ℓ 200	ℓ 80	ℓ 2-10
1	1	1	1	1
1.4	1	1	1	1
2.7	0.95	1	1	1
3.9	0.8	0.85	0.9	1
7.6	0.36	0.77	0.8	1
13	0.154	0.58	0.66	1
31	0.05	0.38	0.58	1
49	0.01	0.26	0.53	1

We can compare these BEAM losses with WMAP and PLANCK losses. For $\ell = 1000$, the most important scale for CMB polarization, at the highest resolution they are about 0.001(WMAP) and 0.05(PLANCK).

To estimate Synchrotron noise at PLANCK frequencies, say, at 3 mm, we should take into account not only the $[f_{\text{PLANCK}}/f_{\text{RATAN-600}}]^3$ factor, but also confusion noise, receivers and $1/f$ noises, and BEAM losses.

The closer we are to the NVSS (FIRST) frequency, 1.4GHz, the deeper background sources cleaning may be done. In contrast, strong interference (and by factor 3-10 more receivers noise) at $f < 3\text{GHz}$, great BEAM losses, prevents to realize frequency cube- factor. We have found, that 7.6-31 cm band has the main priority. The main result at present- is the independent data on the synchrotron Galaxy noise at different frequencies and scales.

Below we show some decimeter results with their sums and differences at all ℓ , in the band, important for polarization on relic grav. waves ($\ell \sim 80$ (Zaldarriaga, 1995)), and at first Doppler peak, $\ell = 200$.

At $\ell 1000$ and $\ell 2500$ we used 7.6cm, but ℓ^{-3} extrapolation from decimeters gives comparable result, in spite of big beam losses. (We should remind, that for RATAN-600 $\ell_{\text{max}} = D/\lambda$, which is much greater, than $S_{\text{eff}}^{-1/2}/\lambda$. Also, in standard approximations of the

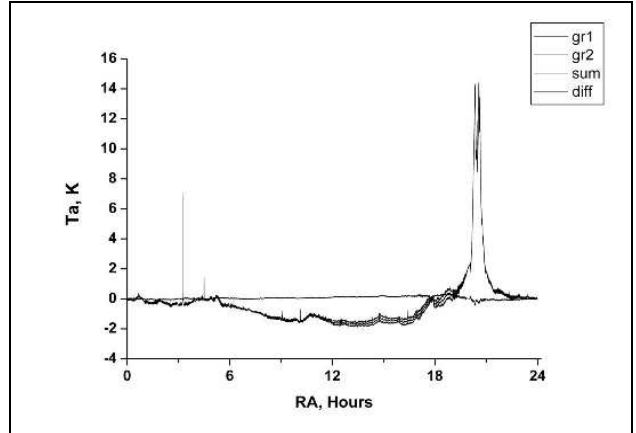


Fig3. 1GHz result. Two independent groups, gr1 and gr2, of observations with mean (“sum”) and difference (“diff”) between groups. About 300 24- hours scans were used. Milky Way dominates at 5^h and 20^h , the minimum is close to the bII maximum region, 12^h . It is the deepest Galaxy cross-cut at high bII (2mK temperature resolution) at high ℓ scales (up to $\ell = 6000$).

BEAM by Gaussian shape, the physically inescapable $\ell_{\text{cut-off}}$ ($u, v_{\text{cut-off}}$ equivalent) theorem is ignoring. For RATAN-600 $\ell_{\text{cut-off}}$ at the lowest frequency, 0.6GHz, is equal to $2\pi * u_{\text{cut-off}} = 2\pi * D/\lambda = 5000$.)

3. Discussion

We have tried to compare our deep data at decimeters with WMAP synchrotron template. We convolved WMAP synchrotron sky with RATAN-600 beams at all frequencies and compared the simulated scans with the real one. We found strong difference between WMAP template and all our scans.

This difference may be interpreted as the wrong spectral index variations template across the sky. This large scale difference may result in the wrong interpretation of the large scale polarization WMAP data (see discussion in (Naselsky, 2003)) at low ℓ ($2 < \ell < 8$).

Great Thomson depth may be not the only interpretation – Galaxy synchrotron polarization is another one. It is not possible to compare our results with WMAP at high ℓ (in WMAP data signal-to-noise ratio < 1 at $\ell > 50$), and we used our own new data here. The main result is that there are no problems with synchrotron polarization at the most interesting for present day experiments at $\ell = 1000$ at frequencies above 10-20 GHz.

At the most important for relic grav. waves polarization, $80 < \ell < 100$, (Zaldarriaga, 1995) much higher frequencies have to be used, but at the central HFI band synchrotron Galaxy noise is below the relic grav. waves noise.

Relic grav. wave experiments are based on the theory, which predicts $0.1\mu\text{K}$ effects, and belongs to the third generation anisotropy experiments, after

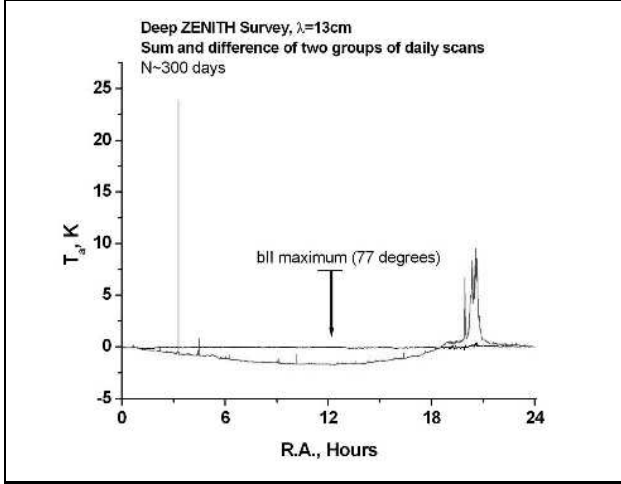


Fig4. Very deep confusion limited cross-cut at 13 cm. 300 daily scans wave used. Note, that at this wavelength the coldest sky is close to the bII maximum point.

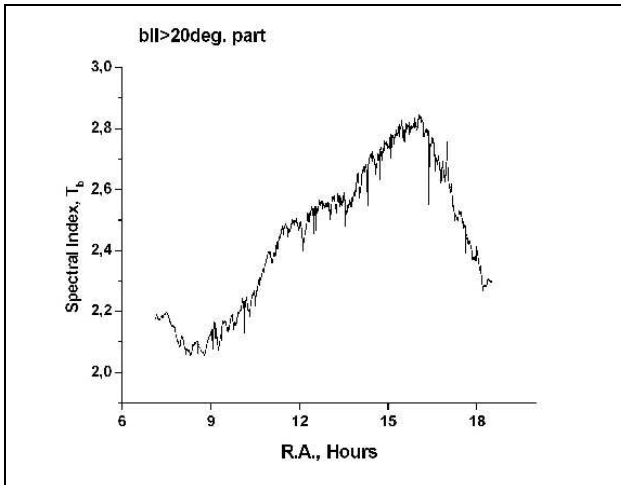


Fig5. Variations of the Galaxy spectral index across the strip at bII > 20° Haslam 73 cm and RATAN-600 7.6 cm data wave used. bII is maximum at R.A. $\sim 13^h$, but it is not the coldest part of sky.

“Sakharov Oscillations” (10-100 μ K), E-mode polarization (few μ K). Spectral features in the CMB anisotropy are the only one field, where effects may be by order of magnitudes weaker (0.01 μ K).

These next generation experiments need in very deep investigations of all screens, involved in observations. Synchrotron space- frequency variations are one of the difficult problems at least in the low frequency band.

The more accurate are synchrotron data, the better estimations of the others screens may be done. Free-free Galaxy noise may be estimated with accuracy above H_α results, which also the subject of dust and temperature space variation. Free-free screen is not (or has very small) polarized, but spinning dust screen can be polarized strongly, and we are going to estimate it effect very soon. Our preliminary data at $\ell = 1000$ where op-

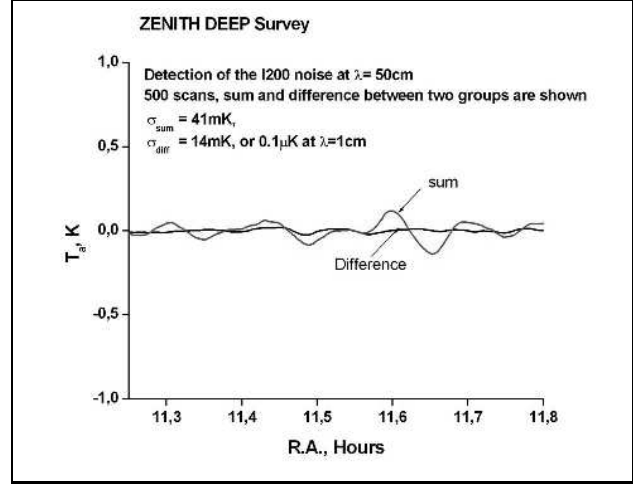


Fig6. First detection of the Synchrotron noise at 0.6 GHz (50cm), $\ell = 200$ scale. The rest of confusion noise is also here, and we suggest 41mK as the upper limit (4mK-8mK for polarization)

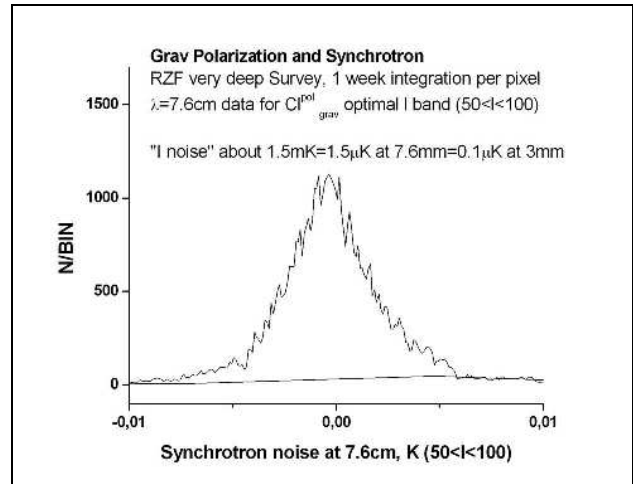


Fig7. Relic Grav. Waves polarization and Galaxy Synchrotron noise at the best ℓ , suggested by theory (Zaldarriaga, 1995) $\ell \sim 80$. In this band we have 1-2 mK noise in I Stocks parameter (as an upper limit); Even with 50% polarization, it corresponds to less than 0.1 μ K at PLANCK HFI.

timistic one (Parijskij, 2003), but now we have spinnius dust much deeper data just at the most active frequencies (20-30GHz, 8GHz).

We stopped now the single-DEC data accumulation when C_l (signal) began greater, than C_l (real noise) and change the strategy to the multi- DEC mode, to reduce the "Cosmic Variance"error and effect of "l-m"confusion (Naselsky et al., 2003). Now we have a more than 500 sq. deg. field with central DEC at the position of 3C84.

The results presented here are the part of the “Cosmological Gene PROJECT” (Parijskij, 2003; <http://www.sao.ru>; Naselsky et al., 1999).

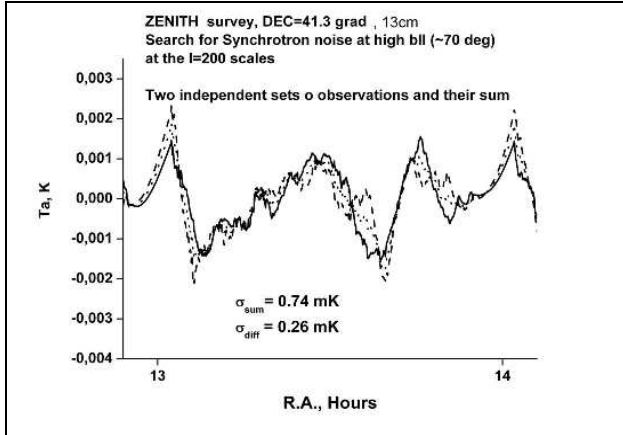


Fig8. 13cm. (2.4GHz). Real Galaxy synchrotron temperature variations at $100 < l < 300$ scales, but with sub-mK amplitude (about 10 nano-K) at PLANCK HFI.

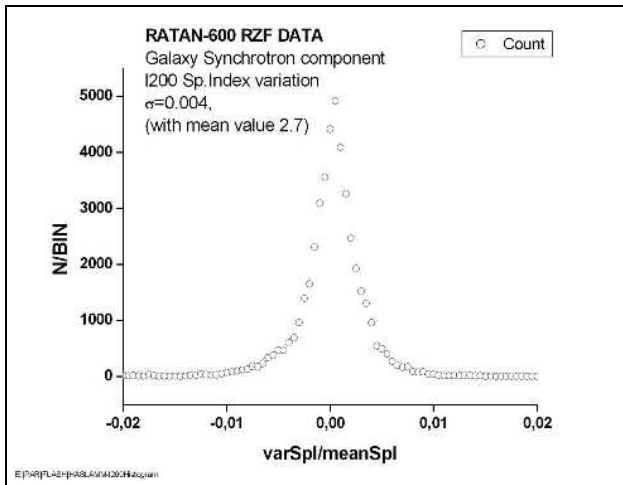


Fig9. Galaxy Synchrotron noise at the main "Sakharov Oscillations" peak, $\ell = 200$. Very small variations of the T_b spectral index were found. This "horizon scale" spectral-space variations limits the accuracy of the CMB spectroscopy.

Acknowledgement

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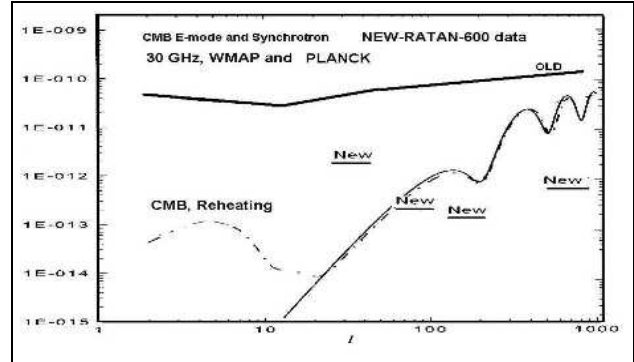


Fig10. E-mode of "Sakharov Oscillations" and new RATAN-600 data on the upper limit of Galaxy synchrotron polarization noise. We extrapolated noise from decimeter RATAN-600 data to 30GHz with better spectral index information. New data are superimposed on the recent world collection of the synchrotron polarization at different scales at 30GHz (Cortiglioni et. al, 2004). In contrast to (Cortiglioni et. al, 2004), no problem exist at $\ell = 1000$ at this PLANCK LFI frequency band, as well as at "Cosmological Gene" main frequency (30 GHz). Problems may appear at 10GHz and below.

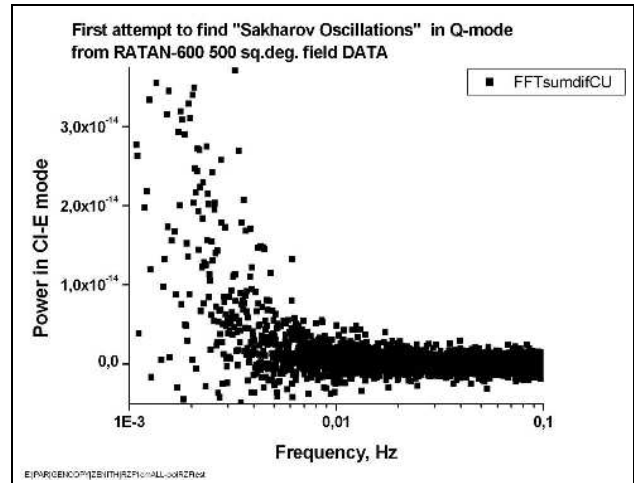


Fig11. 30GHz sky polarization data. FFT of the sum of 500 24-hours scans at 10 adjacent declinations, 12 arcmin apart in 500-degrees area. Strong unidentified polarized signal visible at $\ell < 100$ up to the very low ℓ . It is too strong for synchrotron, and spinning dust and some systematics are under suspicion.

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RATAN-600, new surface
Beam at $\lambda=8\text{mm}$, AK Check

